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that, in the instance of a reversion no larger than this, the applicants might be misled to the extent of £260, or thereabouts, for want of a proper understanding on the part of the actuary of the nature of the transaction. These instances may suffice to show the character of the errors which may be made in the course of our practice, and the necessity of exercising due care and circumspection to avoid them. To many of those I am addressing these precautionary suggestions are, no doubt, needless; but to those who are less practised in this peculiar portion of our professional occupations, they may not be altogether unserviceable.

On a Test for Ascertaining whether an Observed Degree of Uniformity, or the Reverse, in Tables of Statistics, is to be looked upon as Remarkable. By ROBERT CAMPBELL, M.A., *Advocate, Edinburgh, Fellow of Trinity Hall, Cambridge.**

THE following problem was suggested by certain remarks in Mr. Buckle's introductory chapter to his *History of Civilisation.* In that chapter Mr. Buckle remarks upon the striking uniformity usually exhibited by classes of phenomena—such as not only births, deaths, marriages, but such things as those apparently depending upon mere caprice—such as the number of letters annually sent without directions through the Post-office, or those which appear likely to depend on the most capricious and irregular causes, such as murders and suicides; and he proceeds to draw certain moral conclusions from the fact of this uniformity, namely, the existence of certain moral laws, by which a section of the community, definite in number, is always impelled to such acts. But before entering upon a discussion of the legitimacy of such results, there appears to me always a previous question to be solved, namely, whether the observed degree of uniformity is *remarkable* or not. For supposing the observed uniformity to be not more than that which might be expected from events, the occurrence of which to individuals was conceived of as perfectly fortuitous, the whole argument would resolve itself into a pure metaphysical question, from which it would be hopeless to expect any practical issue.

I propose, therefore, the following problem:—To find some test by which we may ascertain whether a certain observed degree of uniformity, or the reverse, in tables which give the numbers yearly occurring of a certain class of phenomena is to be looked upon as remarkable or not; and I propose the following method for finding such a test. Starting from the supposition that we know *nothing* except the total number of such phenomena which have occurred during a certain number of years, let us try to find the degree of uniformity with which we should expect the phenomena to be distributed through the different years. If the uniformity observed in the real tables is much greater than this, we may fairly conclude that there is some cause of this uniformity which we might hope to discover; and further, that if there is any known cause which might tend to produce such uniformity, we may fairly ascribe such uniformity, in part at least, to such cause; and if, on the other hand, we found the figures in the real tables to vary much more widely than we should expect from the knowledge of the mere fact from which we started, we might fairly say that the number in any year which presented such a remarkable deviation *is most likely* assignable to some disturbing cause acting in that particular year.

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* From the *Philosophical Magazine* for November, 1859.

Such positive result will be matter of probability; but of this negative result we may be certain, that if the uniformity thus arrived at is very much the same as that of the real tables, we shall not be justified in drawing any moral inference from that uniformity alone; for it would be shown that such uniformity is only what is to be expected if we know *nothing* except the total sum of the tables.

Suppose, then, that with regard to the statistics of a certain class of phenomena *we know nothing*, except that during a series of a years the number of such phenomena has been found to be ab.

Suppose these to be phenomena presented by, or occurring to, individuals in a population of n persons, which we shall suppose, for the sake of simplicity, to remain nearly constant during the years in question. We will suppose also the phenomena of a kind which are not likely to occur to the same individual more than once in the same year. Of this class would be most of the important phenomena of which tables of statistics furnish numbers. Now, we suppose ourselves totally ignorant of the laws which regulate such phenomena, or rather we suppose it has never occurred to us that they might be regulated by any laws; therefore we do not conceive the same phenomenon to be more or less likely to be presented by the same individual in different years than by different individuals: consequently, we may conceive of the same individual in a different year, for the purposes of this problem, as a different individual.

Now, using the word "probability" in its technical mathematical sense, to say that *we know nothing* except the above datum, is the same as to say that the probability of a given person in a given year presenting the phenomenon is $\frac{b}{n}$. If we call this person A_1, we may now say that the probability of A_1 presenting the phenomenon in the given year is $\frac{b}{n}$.

Now, suppose it known that A_1 presents the phenomenon in the given year: to find the probability of a second given person presenting it in the same year, we must remember that the number of remaining persons favourable to the supposition, any one of whom the person given might be, is $ab-1$, and the whole remaining number of persons is $an-1$. Therefore, calling the second given person A_2, the probability of A_2 presenting the phenomenon in the given year is

$$\frac{ab-1}{an-1};$$

and the probability of his not doing so is

$$1-\frac{ab-1}{an-1}.$$

Therefore the probability of A_1 presenting the phenomenon in any given year, and A_2 not doing so, is

$$\frac{b}{n}\left(1-\frac{ab-1}{an-1}\right).$$

Now, suppose the persons alive in any given year to be A_1, $A_2 \ldots A_n$, it will easily be seen, from the above, that the probability of the phenomenon in that year being presented by A_1, and neither by A_2, A_3, ... nor A_n, is

$$\frac{b}{n}\left(1-\frac{ab-1}{an-1}\right)\left(1-\frac{ab-1}{an-2}\right)\ldots\left(1-\frac{ab-1}{an-n+1}\right).$$

Hence the probability of *one person only* presenting the phenomenon in the given year is

$$b.\left(1-\frac{ab-1}{an-1}\right)\left(1-\frac{ab-1}{an-2}\right)\ldots\left(1-\frac{ab-1}{an-n+1}\right) \quad . \quad . \quad . \quad (1)$$

In a similar way, it may be shown that the probability of A_1, A_2, both presenting the phenomenon in the given year, and neither A_3, A_4 ... nor A_n doing so, is

$$\frac{b}{n}\cdot\frac{ab-1}{an-1}\left(1-\frac{ab-2}{an-2}\right)\left(1-\frac{ab-2}{an-3}\right)\ldots\left(1-\frac{ab-2}{an-n+1}\right).$$

And the probability of *two* persons *only* presenting the phenomenon in that year is

$$\frac{n-1}{2}.b.\frac{ab-1}{an-1}\left(1-\frac{ab-2}{an-2}\right)\left(1-\frac{ab-2}{an-3}\right)\dots\left(1-\frac{ab-2}{an-n+1}\right) \quad . \quad (2)$$

The probability of *three* persons *only* doing so will be

$$\frac{(n-1)(n-2)}{2.3}.b.\frac{ab-1}{an-1}.\frac{ab-2}{an-2}\left(1-\frac{ab-3}{an-3}\right)\left(1-\frac{ab-3}{an-4}\right)$$
$$\dots\left(1-\frac{ab-3}{an-n+1}\right) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

It is easy, therefore, to get the general formula, but it is only necessary to write down the most important one, which is, the probability of *b persons exactly* presenting the phenomenon in the given year. This is

$$\frac{(n-1)(n-2)\dots(n-b+1)}{2.3\dots b}.b.\frac{ab-1}{an-1}.\frac{ab-2}{an-2}\dots\frac{ab-b+1}{an-b+1}$$
$$\left(1-\frac{ab-b}{an-b}\right)\left(1-\frac{ab-b}{an-b-1}\right)\dots\left(1-\frac{ab-b}{an-n+1}\right) \quad . \; . \quad (B)$$

This expression would be obtained from that for the probability of $(b-1)$ persons doing so by multiplying it by the factor

$$\frac{n-b+1}{b}.\frac{ab-b+1}{an-b+1}.\frac{1}{1-\frac{ab-b+1}{an-b+1}}$$
$$.\frac{\left(1-\frac{ab-b}{an-b}\right)\left(1-\frac{ab-b}{an-b-1}\right)\dots\left(1-\frac{ab-b}{an-n+1}\right)}{\left(1-\frac{ab-b+1}{an-b}\right)\left(1-\frac{ab-b+1}{an-b-1}\right)\dots1-\frac{ab-b+1}{an-n+1}},$$

an expression which easily reduces itself to

$$\frac{n-b+1}{b}.\frac{ab-b+1}{an-ab-(n-b)}=1+\frac{b(a-2)+n+1}{(n-b)(a-1)b}.$$

Except, therefore, in the anomalous cases of $a=1$ or $n=b$, which would be easily explained, this expression is always greater than 1.

In the same way, the ratio of the probability of $b+1$ being the number for the year, to that of b being so, is

$$\frac{n-b}{b+1}.\frac{ab-b}{an-b}.\frac{1}{1-\frac{ab-b}{an-b}}$$
$$.\frac{\left(1-\frac{ab-b-1}{an-b-1}\right)\left(1-\frac{ab-b-1}{an-b-2}\right)\dots\left(1-\frac{ab-b-1}{an-n+1}\right)}{\left(1-\frac{ab-b}{an-b-1}\right)\left(1-\frac{ab-b}{an-b-2}\right)\dots\left(1-\frac{ab-b}{an-n+1}\right)},$$

which in the same way reduces itself to

$$\frac{n-b}{b+1}\cdot\frac{ab-b}{an-ab-(n-b-1)},$$

the inverse of which is

$$1+\frac{(a-1)n-(a-2)b+1}{(n-b)(a-1)b},$$

which is also positive.

The number b is, therefore, the *most likely one* to occur in any year. This is simply, in fact, the result which might easily have been foreseen, namely, that the *average* number is the most probable one to occur as the number of the phenomena in any one year; and, consequently, that in a table representing a series of such phenomena, giving the number occurring in each year, we shall expect to find the number which represents the average occurring oftener than any other.

From the above, it is easily seen that, though the expression for the probability of any given number occurring is a very complicated one, yet it will be easy to obtain a comparatively simple expression for the ratio of the probability of any given number occurring to that of the average number occurring. And it can easily be shown that the ratios of the probability of the number b being the one for a given year, to that of $b-1$, $b-2$, $b-3$, and so on, being the numbers, are as follows, viz.:—

b to $(b-1)$,

$$\frac{n-b+1}{b}\cdot\frac{ab-b+1}{an-ab-\overline{n-b}} \quad \ldots\ldots\ldots\ldots \quad (\mathrm{a}_1)$$

b to $(b-2)$,

$$\frac{(n-b+1)(n-b+2)}{b(b-1)}\cdot\frac{(ab-b+1)(ab-b+2)}{(an-ab-\overline{n-b})(an-ab-\overline{n-b+1})} \quad (\mathrm{a}_2)$$

b to $(b-3)$,

$$\frac{(n-b+1)(n-b+2)(n-b+3)}{b(b-1)(b-2)}$$

$$\cdot\frac{(ab-b+1)(ab-b+2)(ab-b+3)}{(an-ab-\overline{n-b})(an-ab-\overline{n-b+1})(an-ab-\overline{n-b+2})}\ . \quad (\mathrm{a}_3)$$

. . . .

and so on.

In a similar manner, we shall find the ratio of the probability of the number b occurring, to that of the numbers b, $b+1$, $b+2$, &c. . . . occurring, to be—

b to $(b+1)$,

$$\frac{b+1}{n-b}\cdot\frac{an-ab-(n-b-1)}{ab-b} \quad .\ .\ .\ .\ .\ .\ .\ .\ .\ .\ . \quad (\alpha_1)$$

b to $(b+2)$,

$$\frac{(b+1)(b+2)}{(n-b)(n-b-1)}\cdot\frac{\{an-ab-(n-b-1)\}\{an-ab-(n-b-2)\}}{(ab-b)(ab-b-1)} \quad (\alpha_2)$$

b to $(b+3)$,

$$\frac{(b+1)(b+2)(b+3)}{(n-b)(n-b-1)(n-b-2)}$$

$$\frac{\{an-ab-(n-b-1)\}\{an-ab-(n-b-2)\}\{an-ab-(n-b-3)\}}{(ab-b)(ab-b-1)(ab-b-2)} \quad (\alpha_3)$$

If we suppose n very large with respect to the other numbers, which is the case of most common occurrence, they will become still more simple. They will then be—

$$(a_1)=\frac{ab-b+1}{(a-1)b},$$

$$(a_2)=\frac{(ab-b+1)(ab-b+2)}{(a-1)^2.b.(b-1)},$$

$$(a_3)=\frac{(ab-b+1)(ab-b+2)(ab-b+3)}{(a-1)^3.b.(b-1)(b-2)},$$

and so on. And

$$(\alpha_1)=\frac{(a-1)(b+1)}{ab-b},$$

$$(\alpha_2)=\frac{(a-1)^2(b+1)(b+2)}{(ab-b)(ab-b-1)},$$

$$(\alpha_3)=\frac{(a-1)^3(b+1)(b+2)(b+3)}{(ab-b)(ab-b-1)(ab-b-2)}.$$

Now, before working out numerical results, there is one observation that is evident on the face of these formulæ. It is evident that, when we get far on in the scale, these numbers will increase *very* rapidly; so that when we get to a number which is *much* greater or less than b, we see that we should expect b to occur with much greater frequency than such number; and when we get considerably away from b (the average number), these figures will become so *immense* that the result will be, that even in a very large table of statistics, we shall not expect such a number to occur at all. We may remark, moreover, that to a very rough approximation the numbers would be symmetrically arranged on each side of b, those above it increasing at first more rapidly, and then less so than those corresponding to the numbers below b. In the case of n *not* being very large, we should observe also, that the numbers increase *more* rapidly than when it is so. An application of this last observation may be the following:—Suppose that in a table of statistics the numbers were found more uniform than should be expected from the whole number of the community. The hypothesis that such phenomena are confined for the most part to a definite section of the community, might in some cases go far to explain such a uniformity.

It is easy to see how the expressions above given will, when worked out, afford a test such as was proposed in the outset. But probably a much more useful application of the problem will be, in the case of the extreme numbers which occur, to be able to tell whether their variation is such as to require explanation from the special circumstances of the particular year.

When we come to work out results numerically, we shall be probably startled at the extremely small probability of a number far removed from the average one which our results will give. It will be much more than in proportion to the moral surprise which it would give us to see such a number in the tables. Why is this? Simply because we started with the hypothesis that we knew *nothing* about laws regulating the phenomena and causing either uniformity or variety. Now this hypothesis was morally incorrect in this respect. For we knew *this* at starting, that such laws *may* exist; and if the degree of uniformity, or the reverse, in the real tables presents a striking contrast to that which we should expect from the result of our hypothesis, we may fairly be led to the conclusion that such laws *do* exist, and that our tables justify us in looking for causes to explain their remarkable features.

For example, take $a=5$, $b=242$, and suppose n large in comparison. (These are the figures referred to in Mr. Buckle's introduction as those representing the suicides in our metropolis for the five years 1846–50 inclusive; the numbers being in 1846, 266; 1847, 256; 1848, 247; 1849, 213; and in 1850, 229, as quoted from the *Assurance Magazine.*)

Our formulæ will then become—

$$a_1 = \frac{5\times 242 - 242 + 1}{4\times 242} = \frac{969}{968},$$

$$a_2 = \quad \cdots\cdots \quad \frac{969\times 970}{968\times 964},$$

$$a_3 = \quad \cdots\cdots \quad \frac{969\times 970\times 971}{968\times 964\times 960}, \text{ and so on.}$$

$$a_1 = \frac{4\times 243}{968} = \frac{972}{968},$$

$$a_2 = \ldots\ldots \frac{972\times 976}{968\times 967},$$

$$a_3 = \ldots\ldots \frac{972\times 976\times 980}{968\times 967\times 966}, \text{ and so on.}$$

Working out the results, we shall find the probability of the number 242 occurring in a given year, to that of 241, 240, &c., occurring, in the following ratios :—

242														
241	1·001	·9989	231	1·348	·7419	221	3·096	·3229	211	12·36	·0809	192	843·2 +	·00149
240	1·007	·9928	230	1·430	·6995	220	3·468	·2884	210	14·65	·0682	182	14060 +	·00007
239	1·019	·9816	229	1·524	·6560	219	3·905	·2561	209	17·45	·0572	172	649500 +	
238	1·036	·9654	228	1·634	·6119	218	4·422	·2261	208	20·92	·0478	162	51170000 +	
237	1·059	·9445	227	1·761	·5677	217	5·036	·1986	207	25·22	·0396	152	7900000000 +	
236	1·088	·9193	226	1·909	·5239	216	5·768	·1734	206	30·58	·0327	142	2445000000000 +	
235	1·123	·8901	225	2·080	·4808	215	6·641	·1506	205	37·26	·0268		&c. &c.	
234	1·166	·8573	224	2·278	·4389	214	7·693	·1301	204	45·76	·0218			
233	1·218	·8213	223	2·510	·3984	213	8·958	·1116	203	56·47	·0177			
232	1·278	·7827	222	2·780	·3596	212	10·490	·0953	202	70·10	·0142			

The numbers for the figures above 242 may easily be similarly worked out, and will present an appearance somewhat symmetrical with the above. It will be thus seen that there are about a dozen numbers, 236 to 248 say, all nearly equally likely to occur with the average one; and about thirty which are at least half as likely to occur as that one. And the above table shows with what enormous rapidity the numbers increase when we get far away from the limit.

The above figures are, of course, obtained by the use of logarithms; it is therefore easy, from the logarithms, to obtain their reciprocals, which are inserted above in the small figures opposite the respective numbers.

These reciprocals will give a key, in any particular case, to find the *absolute* probability of a given number occurring; for it is obvious that the probability of 242 occurring

$$= \frac{1}{1 + \text{sum of their reciprocals}}.$$

Now, the sum of the reciprocals may be found approximately without very great labour; for it will make little difference in the result if we neglect all that come after such a number as that opposite 202.

The probability of 242 occurring having been found, we have the key to any problem, such as "to find the probability of a number *between* 222 and 232 occurring," "to find the probability of a number less than 222 occurring," &c.: *e.g.*, to find the probability of a number between 212 and 220 inclusive occurring in a given year, "add the reciprocals opposite the numbers, divide by 9, and multiply the result by the probability of 242 occurring," &c.

I should suggest as likely to be a very useful application of the above, the solution of problems relating to the amount of capital requisite to ensure the stability of an Insurance Office with regard to fortuitous fluctuations, problems with regard to laying aside of bonus additions to policies, &c., especially where the statistics already obtained with regard to the particular class of risks are scanty.

The fundamental expressions receive another simplification if a is *large;* that is, supposing us to be supplied with tables extending through a great number of years. The expressions then become—

$$a_1=\frac{n-b+1}{b}\cdot\frac{b}{n-b},$$

$$a_2=\frac{(n-b+1)(n-b+2)}{b(b-1)}\left(\frac{b}{n-b}\right)^2,$$

$$a_3=\frac{(n-b+1)(n-b+2)(n-b+3)}{b(b-1)(b-2)}\left(\frac{b}{n-b}\right)^3, \text{ and so on.}$$

$$a_1=\frac{b+1}{n-b}\cdot\frac{n-b}{b},$$

$$a_2=\frac{(b+1)(b+2)}{(n-b)(n-b-1)}\left(\frac{n-b}{b}\right)^2,$$

$$a_3=\frac{(b+1)(b+2)(b+3)}{(n-b)(n-b-1)(n-b-2)}\left(\frac{n-b}{b}\right)^3, \text{ and so on.}$$

These results might have been obtained more directly by neglecting a from the first. If the number of years was large, we should have very nearly the probability of A_1 presenting the phenomenon, and A_2 *not* doing so,

$$=\frac{b}{n}\left(1-\frac{b}{n}\right), \text{ and so on.}$$

It has been found best to state the above problem starting from the point which suggested it; but, from the results obtained, it is thought the problem is capable of some more practical application. If the statements were strictly kept clear of all metaphysical ideas, what is proved amounts to this:—

If, among a set of n persons, an in number, there are ab who have some special peculiarity; then, if the persons are arranged in a sets (say, set 1st, 2nd, 3rd, &c.), each set containing n persons, and if this be done in all possible ways, the number of arrangements which will throw exactly b of the peculiar individuals into a given set (say the 3rd), will be to the number of arrangements which will throw exactly $b-1$, $b-2$, &c., $b+1$, $b+2$, &c., of the persons into that set are as the numbers opposite (a_1), (a_2), &c., (a_1), (a_2), on pp. 320, 321.

In the following problem, we shall find the reciprocals of these more convenient for use. We shall call them (ϕ_1), (ϕ_2), &c., and (ψ_1), (ψ_2), &c.

Suppose we know that a set of $(a-1)n$ persons contains $(a-1)b$ of a particular class, and we take n more persons, whom we suppose individually as equally likely to belong to that class with the former; and let us suppose that they contain $b+ax$ persons of the kind required, and we want to find the probable limits of the value of x.

The whole an persons will contain $ab+ax$ of the required class, so that the average of that class in each set, if they were all divided into n sets, would now be $b+x$.

But supposing for an instant that we only knew that in the whole an persons the number belonging to the class was $ab+ax$; then the probability of the number $b+ax$ exactly of the class being in a given set (such as the set we supposed last taken in) would be to that of the number $b+x$ exactly being in the set, in the ratio

$$\left\{\psi_{ax-x}\right\}_{b+x}.$$

The $(b+x)$ below indicating that $b+x$ is to be written for b in the expression on p. 321.

And, writing $b+x$ for b in the expression for B, on p. 319, we have—

$$\left.\begin{array}{r}\text{Absolute probability of } b+ax \text{ exactly}\\ \text{of the class being in the set} \quad .\end{array}\right\} = \left\{\psi_{ax-x}\right\}_{b+x}(\mathrm{B})_{b+x}.$$

This will hold for any particular values of x, say $x=x_o$ and $x=o$; and, remembering that the hypothesis $x=x_o$ is the same as saying that $b+x_o$ is the average, and $x=o$ that b is the average, we have—

$$\left.\begin{array}{r}\text{Probability of } b+ax_o \text{ exactly of the class}\\ \text{being in the set } (b+x_o \text{ being the average})\end{array}\right\} = \left\{\psi_{ax_o-x_o}\right\}_{b+x_o}(\mathrm{B})_{b+x_o}.$$

But the concurrence of the circumstances of $b+ax_o$ exactly of the class being in the set, with $b+x_o$ being the average, is the same thing as the concurrence of $b+ax_o$ being the number in the set, and of the other sets together containing $(a-1)b$. But the last is true by hypothesis: therefore—

$$\left.\begin{array}{l}\text{Probability of } b+ax_o \text{ exactly of the class}\\ \quad\text{being in the set, \textit{under the hypothesis}}\\ \quad\text{\textit{of the problem}} \quad . \quad . \quad . \quad .\end{array}\right\} = \left\{\psi_{ax_o-x_o}\right\}_{b+x_o}(\mathrm{B})_{b+x_o}.$$

And, under the same hypothesis—

$$\frac{\text{Probability of } b+ax_o \text{ exactly}}{\text{Probability of } b \text{ exactly}} = \frac{\{\psi_{ax_o-x_o}\}_{b+x_o}(\text{B})_{b+x_o}}{\text{B}}.$$

Now, if we had numerical values given for *a* and *n*, it might be possible for a limited number of values of *x* (say 1, 2, 3, 4, 5), to work out the above formula sufficiently for determining the above ratio approximately; and, in most cases, very few values worked out would be sufficient for any practical purpose, at least, if *a* is not less than 5 or 6.

On the Purchase of Life Assurance Policies as an Investment. By ARCHIBALD DAY, *Actuary of the London and Provincial Law Assurance Society, and Fellow of the Institute of Actuaries.*

[Read before the Institute of Actuaries, 2nd January, 1860.]

AN allusion made by Mr. Jellicoe to this subject, in a paper read before the Institute of Actuaries on the 28th November, has induced me to place on record the conclusions at which I had arrived after a somewhat recent consideration of the question.

It appears to me that the buyer of a policy by way of investment, in considering the price at which he should purchase, should come to his decision entirely independent of what might be the Office value. The two values have no connexion whatever one with another. In the one case the purchaser is about to make an investment; in the other, the Office proposes to redeem a liability.

The assumption is that the life on which the policy depends is an average one; or, at any rate, that the proposed purchaser knows nothing to the contrary. Speculations may, indeed, be made in the purchase of policies where the health of the life insured is known to be impaired; or prices exceeding the Office values may be paid for policies immediately prior to a division of profits, for the sake of surrendering them to the Office, after the declaration of bonus, at an increased price; but with these cases I do not now propose to deal. My present object is to show what sum should be given by a person contemplating a permanent investment and expecting to obtain a reasonable rate of interest for his money.

Viewing the question in this light, the purchaser of a policy has two things to consider—

1. The purchase of an absolute reversion payable on the death of a given life;